COMPUTATIONAL STUDY ON SHEAR STRENGTHENING OF RC CONTINUOUS BEAMS USING CFRP SHEET

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Especially dedicated to:

For my Father, Mother and brother

Words cannot express everything you have done for me ... thank you so much

For all of my support to achieve this research. My wife, sisters, friends and all those

Who have been a great

Help in the completion of this thesis

My love for you all remains forever…

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ABSTRACT

This research studied the feasibility and effectiveness of a new method of strengthening existing RC continuous beams in shear by using CFRP strips. The CFRP composite strips were used to strengthen concrete externally at a known failure plane to resist shear stresses in shear friction. All beams were design to fails in shear with av/d 2.5. This research describes the computational study on shear strengthening of RC continuous beams using CFRP strips. In this study, a computational program consisting of 5 beams were performed subjected to experimental program with the same size and details of the beams where the experimental study was performed by other student in the laboratory. Here in this part the study done through simulation by ABAQUS Software version 6.9. Therefore, this research aims to investigate the effectiveness of using externally bonded CFRP strips in repair and strengthen of RC continuous beams and also to know the behavior of RC continuous beams strengthened in shear with CFRP sheet. So in this study there are five specimens with different CFRP wrapping scheme as 90 degree and 45 degree with three sides and four sides each beam. The computational results were compare with the experimental results that obtained by other student. The computational results show great agreement with the experimental results.

ABSTRAK

Kajian ini dijalankan bagi mengkaji keberkesanan kaedah baru bagi pengukuhan ricih rasuk selanjar konkrit bertetulang yang sedia ada menggunakan lajur-lajur CFRP. Lajur-lajur CFRP digunakan untuk pengukuhan concrete secara luaran untuk menahan tegasan ricih. Kesemua rasuk direkabentuk untuk gagal dalam ricih dengan av/d 2.5. Kajian ini menerangkan kajian simulasi terhadap pengukuhan ricih bagi rasuk selanjar konkrit bertetulang menggunakan lajur-lajur CFRP. Dalam kajian ini, program simulasi terhadap lima rasuk selanjar telah dijalankan dimana rasuk-rasuk tersebut adalah sama saiz dan berpandukan kepada kajian makmal yang telah dijalankan oleh pelajar lain. Kajian ini dijalankan dengan menggunakan simulasi computer ABAQUS versi 6.9. Kajian ini dijalankan bagi menyiasat keberkesanan pengukuhan secara luaran menggunakan lajur-lajur CFRP terhadap rasuk selanjar konkrit bertetulang disamping untuk mengenalpasti kelakuan rasuk selanjar konkrit bertetulang yang diperkukuhkan menggunakan lajur-lajur CFRP. Oleh itu, terdapat lima rasuk terlibat dimana setiap satunya berbeza daripada orientasi lajur-lajur CFRP iaitu sama ada 45 darjah atau 90 darjah dan juga berbeza dari segi sama ada dibalut empat sisi atau tiga sisi. Kajian simulasi kemudiannya dibandingkan dengan kajian makmal yang telah dijalankan oleh pelajar lain. Kajian simulasi didapati menunjukkan hasil yang memuaskan setelah dibandingkan dengan kajiam makmal.

CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 RESEARCH METHODOLOGY

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

1.1 Introduction

During the past 30 years, it has been necessary to strengthen increasing numbers of reinforced concrete beams. In the early days, this was achieved by bonding thin steel plates to beam soffits or sides to enhance the flexural or shear strength. However, steel has numerous disadvantages, the most obvious of which is its great weight. In the late 1980s, this material began to be replaced by carbon fiber-reinforced polymer (CFRP) plates which were much lighter and stronger than steel.

The majority of early investigations into (CFRP) were directed at flexural strengthening and little research was undertaken into the use of CFRP for shear strengthening. However, the publication of Concrete Society Technical Report 55 Design guidance for strengthening concrete structures using fiber composite materials briefly describes some applications and provides design guidance on the use of fiber composites to enhance shear strength.

This study covers the computational study on shear strengthening of reinforced concrete continuous beams using CFRP sheet and tends to reduce the problems regarding shear failure and a sudden collapse of a structure.

1.2 Problem statement

Shear failure of reinforced concrete (RC) is very dangerous and occurs suddenly with no advance warning. Therefore, it is important to understand the behavior of shear of reinforced concrete continuous beams. This is includes the behavior of the beam before and after crack. Traditionally, repair of reinforced concrete is done by using steel plate as the external strengthened mechanism. However, steel plate shows weaknesses in terms of corrosion of the steel plate due to the environment. Therefore, this study tends to use CFRP as it is has better performance in terms of the reaction with the environment compared with steel plate. In this study, a computational program consisting of 5 beams will be performed subjected to experimental program with the same size and details of the beams where the experimental study was performed by other student. The CFRP composite strips were used to strengthen concrete externally at a known failure plane to resist shear stresses in shear friction. All beams were design to fails in shear with av/d 2.5. This paper describes the computational study on shear strengthening of RC continuous beams using CFRP sheet.

1.3 Objectives of project:

1) To investigate the effectiveness of using externally bonded CFRP strips in repair and strengthen of RC continuous beams.
2) To study the behavior of RC continuous beams strengthened in shear with CFRP sheet using finite element analysis.
3) To investigate the shear behavior of RC continuous beams repair with different CFRP wrapping scheme.

1.4 Scope of project

1) This study involves a finite element modeling and analysis of RC continuous beams externally strengthened with CFRP sheet.
2) Computational study using ABAQUS software.

3) The results from finite element analysis using ABAQUS software will be compared with laboratory results which performed by another student.
4) The CFRP wrapping scheme will involve wrapping four sides and wrapping three sides of the beams.
5) All beams were designed to fails in shear with av/d 2.5.

1.5 Significance of Research

The importance of this research is it aims to contribute on the study of shear strengthening of RC continuous beams using Carbon Fiber Reinforced Polymer (CFRP) to increase the shear capacity of the beams. This study will also investigate the behavior of reinforced concrete continuous beams strengthened in shear with CFRP sheet by using finite element analysis. Finite element analysis (FEA) can analyze the design in detail, saving time and money by reducing the number of prototype required.

CHAPTER 2

2.1 Introduction of FRP

There are considerable numbers of existing reinforced concrete structures in world that do not meet current design standards, because of inadequate design and/or construction error or need structural upgrading to meet new seismic design requirements. Retrofitting of flexural concrete elements is traditionally accomplished by externally bonding steel plates to concrete. Although this technique has proved to be effective in increasing strength and stiffness of reinforced concrete elements, yet it has the disadvantages of being susceptible to corrosion and difficult to application and installation. Recent development in the field of composite materials, together with their inherent properties, which include high specific tensile strength, good fatigue and corrosion resistance and ease of use, make them an attractive alternative to steel plates in the field of repair and strengthening of concrete elements.

The use of fiber reinforced polymer (FRP) composites for strengthening reinforced concrete(RC) structure was first investigated as an alternative to steel plate bonding for beam strengthening at the Swiss Federal Laboratory for Materials Testing and Research (EMPA) (Meier et al. 1993) where tests on RC beams strengthened with CFRP plates started in 1984.

After this many research studies have been carried out and awareness, trust and confidence on FRP composites increased among the professionals particularly in USA, Japan and the countries of Europe. Today they are many case studies in these countries where this technique has achieved desired results. Corrosion of steel reinforcement embedded in concrete structures is considered to be the main cause of structural concrete deterioration. Chloride ions produced by the corrosion of the steel reinforcement can cause serious damage to surrounding concrete and also depreciate the strength of the corroded member. In many regions the corrosion of the steel reinforcement is accelerated by the use of deicing salts and other chemicals to prevent freezing. Many various approaches have been attempted to control the corrosion of the reinforcing steel: epoxy coated rebar; protection increased cover use of polymer concretes etc. However, none of these approaches provides a permanent solution as they all still incorporate the usage of corrosive steel. Recently advances in fiber reinforced plastics (FRP) have made replacing steel reinforcement with non-corrosive FRP's a viable alternative.

CFRP's offer many advantages as compared to steel reinforcement including high strength to weight ratio, excellent fatigue characteristics, corrosion resistance, electromagnetic neutrality, low axial coefficient of thermal expansion, and handle ability due to its light weight.

2.2 Fiber reinforced polymer

2.2.1 History of FRP

FRP composites are the latest version of the very old idea of making better composite material by combining two different materials that can be traced back to the use of straw as reinforcement in bricks used by ancient civilizations (e.g. Egyptians in 800). The development of FRP reinforcement can be found in the expanded use of composites after World War II: the automotive industry first introduced composites in early 1950's and since then many components of today's vehicles are being made out of composites. The aerospace industry began to use FRP composites as lightweight material with acceptable strength and stiffness which reduced the weight of aircraft structures such as pressure vessels and containers. Today's modern jets use large components made out of composites as they are less susceptible to fatigue than traditional metals. Other industries like naval, defense and sporting goods have used advanced composite materials on a widespread basis: pultrusion offered a fast and economical method of forming constant profile parts, and pultruded composites were being used to make golf clubs and fishing poles. Only in the 1960s, however, these materials were seriously considered for use as reinforcement in concrete.

More recently, EOCRETE has headed the European effort with research and demonstration projects. In Japan more than 100 commercial projects involving FRP reinforcement were undertaken up to the mid-1990s (ACI Committee 440, 2001). The 1980s market demanded nonmetallic reinforcement for specific advanced technology; the largest demand for electrically nonconductive reinforcement was in facilities for MRI (Magnetic Resonance Imager) medical equipment. FRP reinforcement became the standard in this type of construction. Other uses developed as the advantages of FRP reinforcement became better known and desired, specifically in seawall construction, substation reactor bases, airport runways, and electronics laboratories (Brown and Bartholomew 1996).

2.2.2 Definition of FRP

FRP composites consist of high strength fibers embedded in a polymer resin. The fibers are the main load-carrying element and have a wide range of strengths and stiffnesses with a linear stress-strain relationship up to failure. Fiber types typically used in the fabrication of FRP composites for construction are carbon, glass, and aramid. All these fibers are available commercially as continuous filaments.

The polymer resin surrounds and encapsulates the fibers to bind them together, protect them from damage, maintain their alignment, and allow distribution of load among them. Polymers are available as two categories; thermosetting polymers (e.g. epoxy and polyester) and thermoplastic polymers (e.g. nylon).

FRP composites have become more popular and accepted by designers, contractors, and owners due to combinations of their unique characteristics. FRP composites have significantly higher strength-to-weight ratio than metals and other construction materials. In addition, these materials are non-corrosive, non-magnetic, and generally resistant to chemicals. A comparison among carbon FRP, aramid FRP (AFRP), and glass FRP (GFRP) sheets (based on fiber area only), and reinforcing steel in terms of stress strain relationship is illustrated in next figure

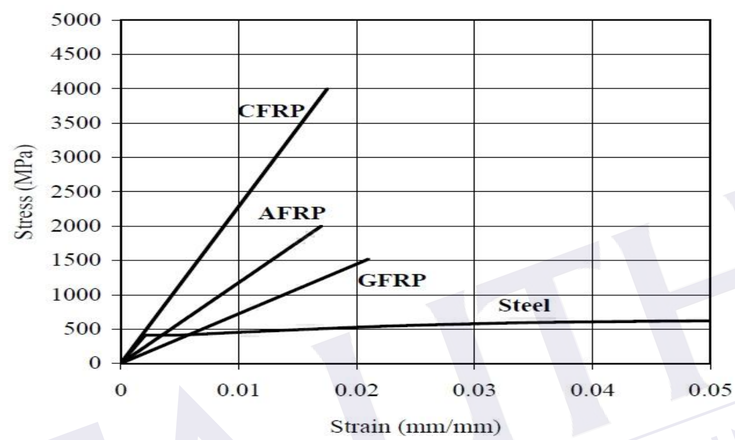

Figure .2.1: Comparison among CFRP, AFRP, and GFRP sheets and reinforcing steel in terms of stress-strain relationship.

2.2.3 Types of CFRP

There are three types of CFRP

GFRP - Glass fibers typically have a Young modulus of elasticity (70 GPa for E-glass) lower than carbon or aramid fibers and their abrasion resistance is relatively poor. In addition, a glass fiber has low fatigue strength. To enhance the bond between fibers and matrix, as well as to protect the fibers and moisture, fibers undergo sizing treatments acting as coupling. Such treatments are useful to enhance durability and fatigue performance (static and dynamic) of the composite material. FRP composites based on fiberglass are usually denoted as GFRP.

AFRP – Aramid fibers are organic fibers, made of aromatic polyamides in an extremely orient form. Due to the anisotropy of the fiber structure, compression loads promote a localized yielding of the fibers resulting in fiber instability and formation of kinks. Aramid fibers may degrade after extensive exposure to sunlight, losing up to 50 % of their tensile strength. In addition, they may be sensitive to moisture. Their creep behavior is similar to that of glass fibers, even though their failure strength and fatigue behavior is higher than GFRP. FRP composites based on aramid fibers are usually denoted as CFRP. For strengthening purposes in civil engineering carbon fibers are the most suitable.

CFRP - Carbon fibers are used for their high performance and are characterized by high Young modulus of elasticity as well as high strength. They have an intrinsically brittle failure behavior with a relatively low energy absorption; nevertheless, their failure strength are larger compared to glass and aramid fibers. Carbon fibers are less sensitive to creep rupture and fatigue and show a slight reduction of the long-term tensile strength. FRP composites based on carbon fibers are usually denoted as CFRP.

2.2.4 The uses of FRP

FRP composites can be produced by different manufacturing methods in many shapes and forms. The most popular ones for concrete reinforcement are bars, prestressing tendons, pre cured laminates shells, and fiber sheets. FRP bars and tendons are currently produced with sizes and deformation patterns similar of those of steel bars, strands and solid wires.

They are commonly used for internal concrete reinforcement. FRP pre-cured laminates shells and sheets are commonly used as external reinforcement for repair and strengthening purposes. Here are some common uses in the field of engineering:

1) To resolve corrosion problems in reinforcing steel
2) To increase the efficiency of repair work for the deteriorating RC infrastructure, professionals have turned to alternative materials such as FRP composites.
3) The interest in the use of composites is attributable to declining manufacturing costs combined with ease and speed of installation.

The structural design and thus the production of structural elements made of reinforced concrete is based on forces and loads current in codes of the time. However, during the service life of a structure, various circumstances may require that the service loads are changed due to:

1) A modification of the structure: cutting of holes in slabs or beams.
2) A different use of the structures: from offices to library.
3) Ageing of the construction materials.
4) Deterioration of the concrete caused by reinforcement corrosion.
5) Cutting of pre- or post- stressed reinforcement cables.
6) Fire damages.
7) Upgrading of building codes.
8) Earthquake design requirements.

The CFRP laminates are used for the post-strengthening of structures to increase the load bearing capacity of structural components (increase of bending tensile force). The increased flexural capacity results in reduced deflections and the reduction in crack propagation. The use of carbon fiber plate has distinct advantages over the use of conventional steel plate and provides the designer with a unique freedom of design. Carbon fiber plates can be applied to both wooden and concrete beams, columns, slabs and walls for permanent structural reinforcement. This is in both the positive as well as negative moment.

2.2.5 Advantages and disadvantages of FRP

Advantages of FRP reinforcement:

1) High longitudinal tensile strength (varies with sign and direction of loading relative to fibers)
2) Corrosion resistance (not dependent on a coating)
3) Nonmagnetic
4) High fatigue endurance (varies with type of reinforcing fiber)
5) Lightweight (about 1/5 to 1/4 the density of steel)
6) Low thermal and electric conductivity (for glass and aramid fibers)

Weight advantages

another very distinct advantage of FRP is it is low weight to strength ratio as rule of thumb for the same strength FRP will weigh approximately one seventh as much as steel, and half as much as aluminum. Light weight properties are important when considering the cost and ease of installation especially for pipe and tanks. FRP's inherent light weight is an advantage when equipment must be mounted on existing structures such as scrubbers on mezzanines applications such as FRP tank trailers.

High Strength

While not as important for corrosion resistant equipment, high strength does play a major role in the design of FRP equipment for such applications as missiles, pultruded shapes, etc. for filament wound pipe and duct, the high strength gives the light weight features discussed earlier. You will often see FRP equipment, especially filament wound equipment, advertised as stronger than steel for pressure application, FRP's high strength properties can be a major advantage.

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